# Lecture 4-2 Surface Micromachining

- **Definition: A technique for fabricating three-dimensional micromechanical structures from mutilayer stacked and patterned thin film.**

  **Layer stacking and sacrificial etching:**

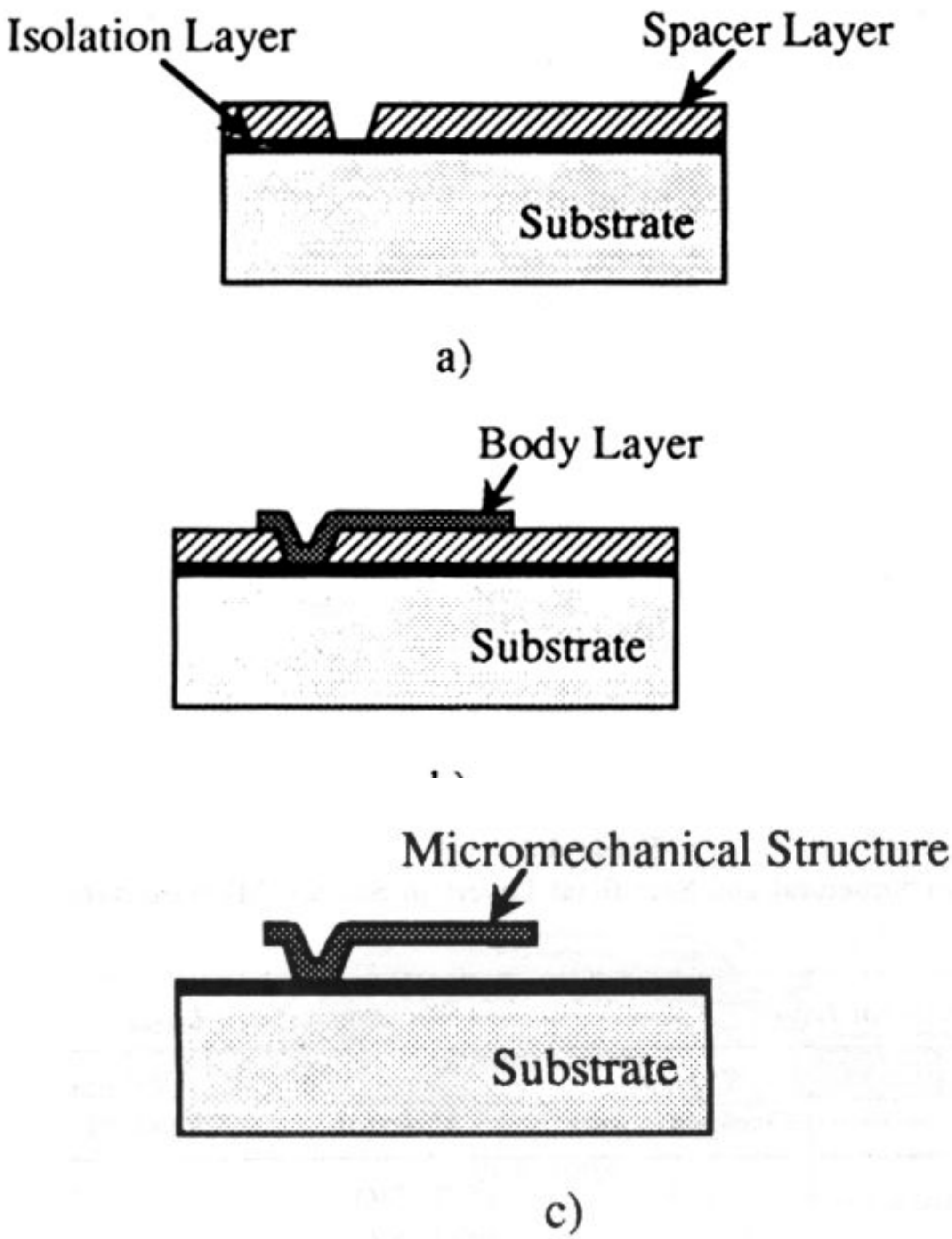



**Figure 4.1** Surface micromachining: (a) patterned sacrificial layer; (b) patterned structural layer; (c) suspended beam after sacrificial etching.

**Sealing:**

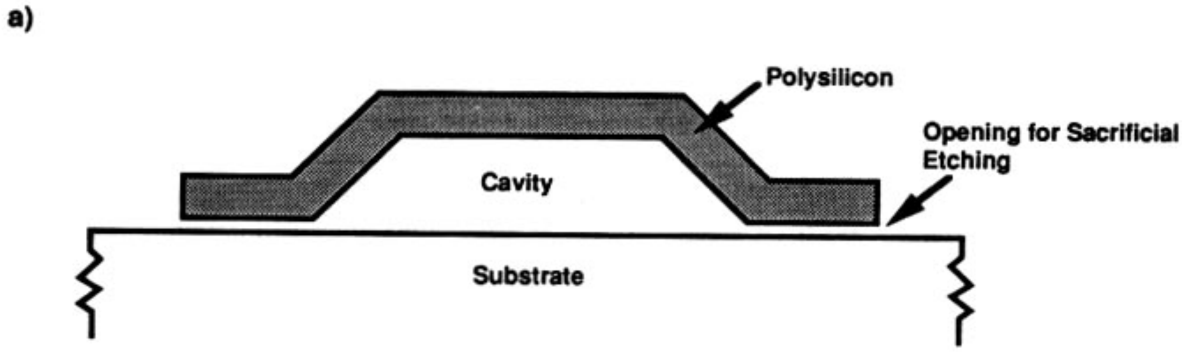



**Figure 4.2** Sealing: (a) cavity after sacrificial etching; (b) reactive sealing; (c) sealing by deposition.

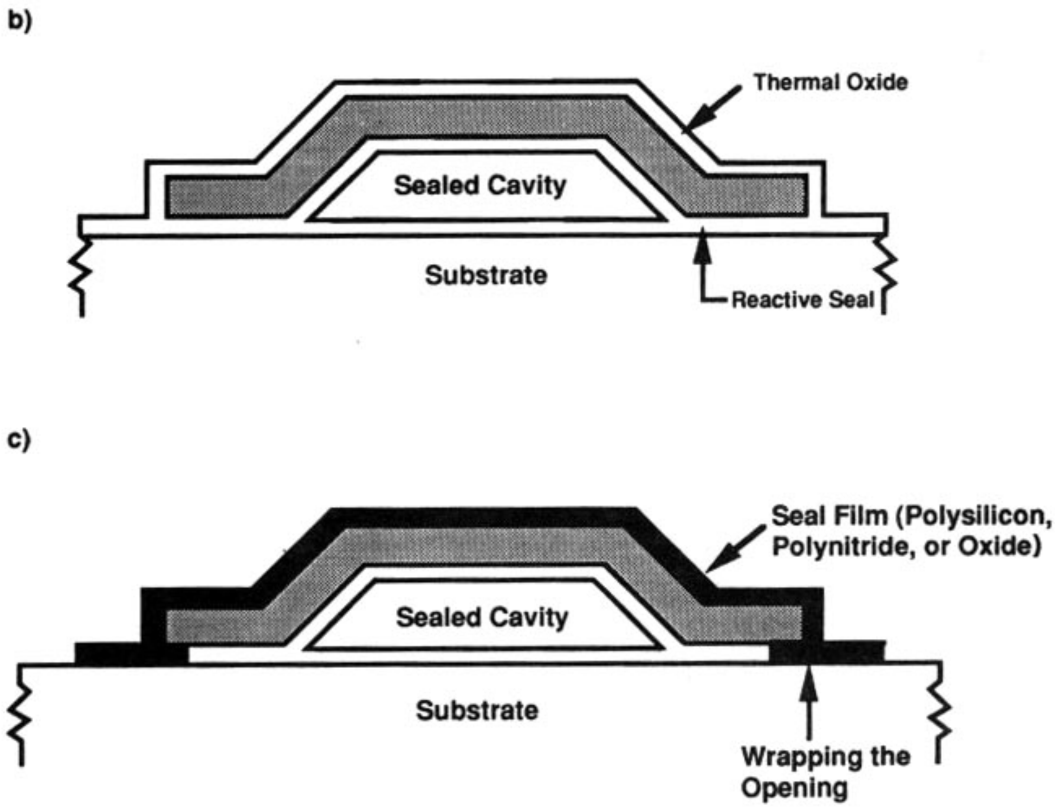



**Figure 4.2** continued.

- **Materials: polysilicon, silicon nitride, silicon dioxide, polyimide, tungsten, molybdenum, amorphous silicon carbide, TiNi alloy, nickel-iron permalloy, Aluminum, or composite films, such as polysilicon-ZnO, polysilicon-silicon nitride-polysilicon.**

- **Comparison to bulk micromachining:**
  1. **Produce smaller sensors or actuators, scale ~1-hundreds of µms**
  2. **Share with many current IC processes**
  3. **Better feature definition, thickness can be controlled in submicron, however, it can be a problem to get thickness more than 10 µm**
  4. **Selection from many materials…**
- **Sacrificial layers:**

**Table 4.2**
Combination of Structural and Sacrificial Layers in Surface Micromachining

| *Structural Layer* | | *Sacrificial Layer* | |
|---|---|---|---|
| *Material* | *Typical Thickness (µm)* | *Material* | *Typical Thickness (µm)* |
| Polysilicon | 1–4 | PSG, $SiO_2$ | 1–7 |
| $Si_2N_4$ | 0.2–2 | PSG, $SiO_2$ | 2 |
| $SiO_2$ | 1–3 | Polysilicon | 1–3 |
| Polyimide | 10 | Al | 1.5–3 |
| W | 2.5–4 | $SiO_2$ | 8 |
| Mo | 0.5 | Al | 0.7 |
| SiC | 1.5 | $SiO_2$ | 1.5 |
| TiNi | 8 | Polyimide or | 3 |
| | | Au | 2 |
| NiFe | 2.5 | Al or | 7 |
| | | Cu | 7 |
| PolySi–ZnO | 2–0.95 | PSG | 0.6 |
| PolySi–$Si_3N_4$–PolySi | 1–0.2–1 | PSG | 2 |

- **Properties of polysilicon:**

1. **Deposited by LPCVD, PECVD, APCVD system at temperature from 530˚C-700˚C. Transition temperature at 560-600˚C from amorphous to polycrystalline silicon.**
2. **Grain size decrease from 530-630˚C and increase from 630-700 ˚C, highest stress and resistivity also show up at 630˚C.**
3. **Film stress:**
   **fully amorphous and fully polycrystalline LPCVD poly silicon: compressive stress, -300~-500 MPa**
   **transition polysilicon : film stress ranges from tensile to compressive. (+500~-500 Mpa)**
   **Stress gradient: bent upward**

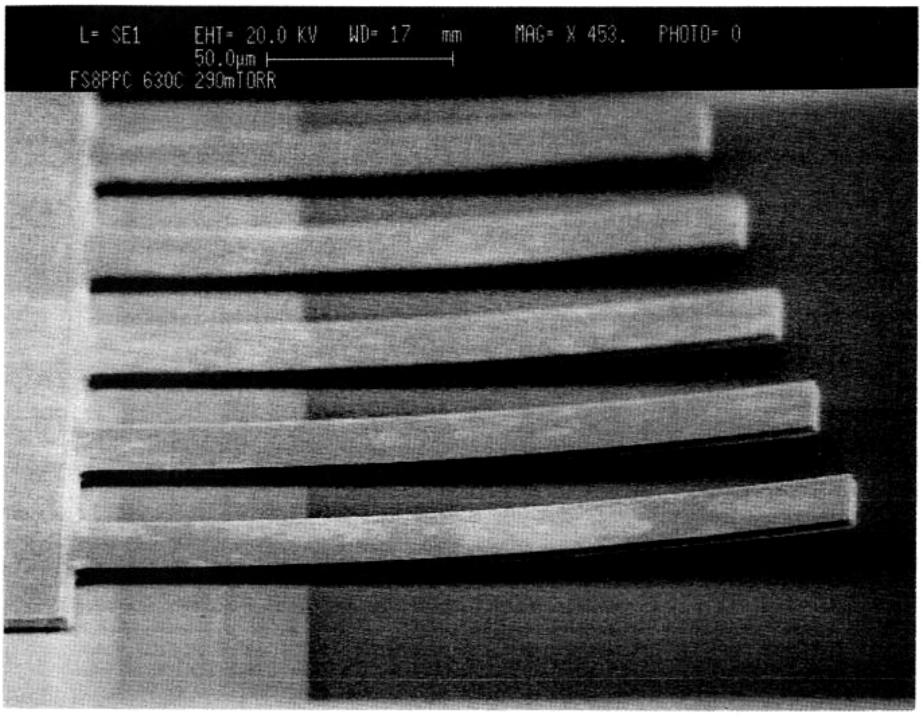



**Figure 4.6** SEM micrograph of 2.0-μm thick polysilicon film deposited at 630°C and 290 mtorr total pressure.

4. **Annealing of undoped polysilicon films**
   **Long time annealing at temp from 650-1050 ˚C can reduce compressive stress. However, the film grain size dose not change much during the annealing process.**

5. **Doping: (mostly Phosphorus)**
   **Reduce film resistivity up to 0.04, promotion of crystallization,**
   a. **In situ: reduce total process steps, offer a flat concentration profile over the thickness of film, precision dopant concentration control. tensile stress from 500-100 MPa.**
   b. **Ex-situ: doping from PSG or predeposition. Moderate temperature causes film <u>bend down</u>-increase compressive stress.**

- **Sacrificial etching:**
  **PSG (phosphosilicate glass) from LPCVD etching rate in 1.25% HF: 0.55-1 µm/min**
  **Reaction limit: ~t**
  **Diffusion limit:~$t^n$, n<1.**

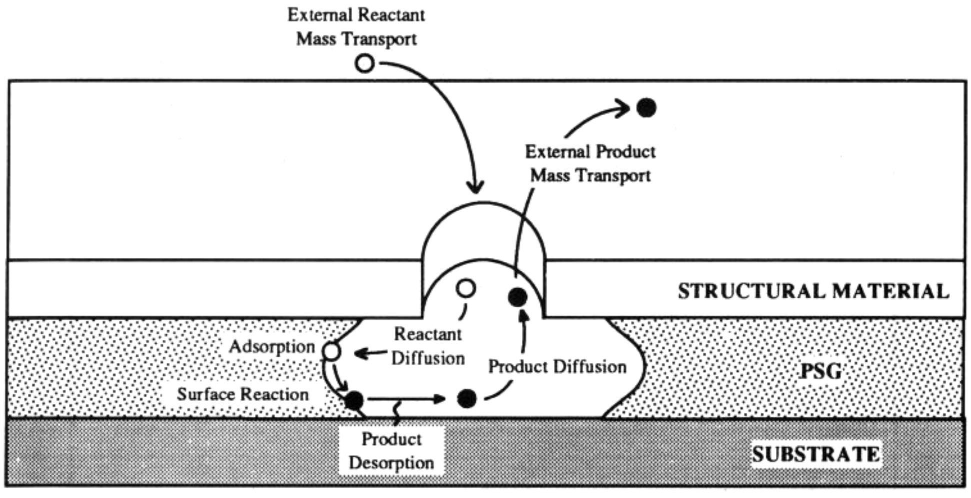
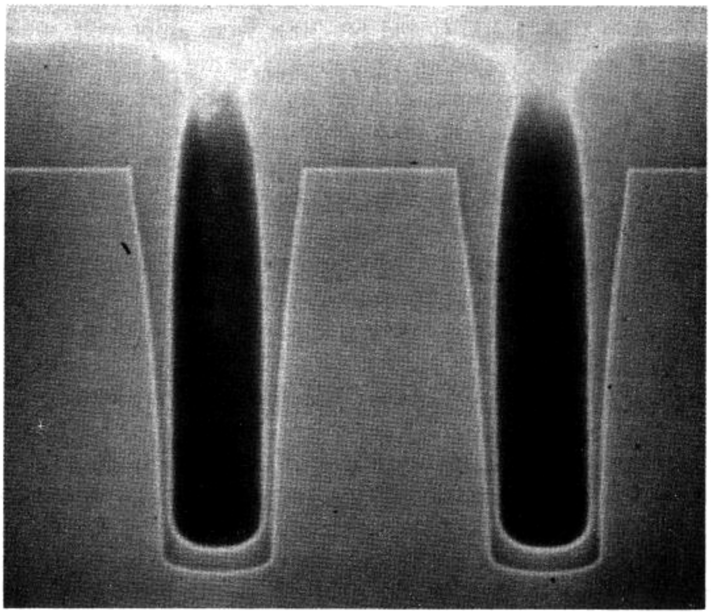
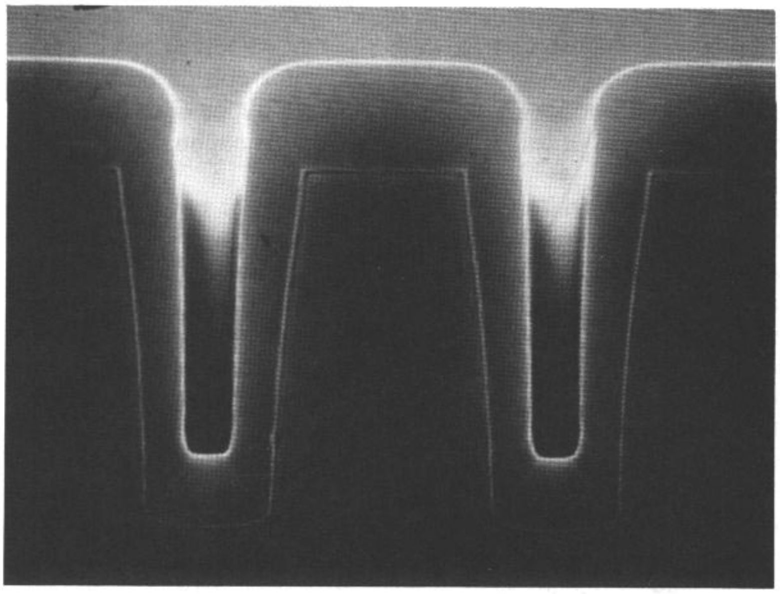



**Figure 4.13** Schematic representation of PSG sacrificial etching mechanism.

- **Step coverage**



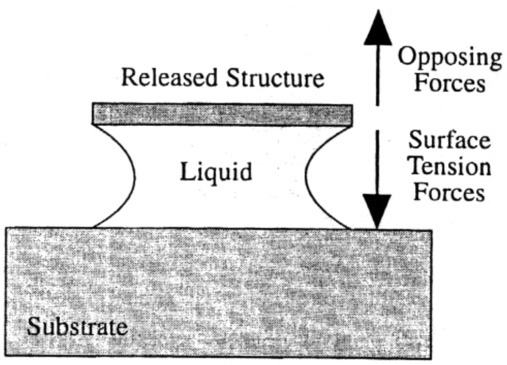


- **Stiction:**

**Caused from water capillary force, which draw microstructures toward the substrate, then other forces develop between the contact surfaces.**

**Solution:**

1. **low surface tension solution, such as methanol, IPA**
2. **Heat up when drying**
3. **supercritical sublimation**
4. **surface treatment-hydrophobic: SAM (self assembly monolayer)**
5. **Structure modification: bump, temporary supporting materials**
6. **Gas type releasing: $N_2$ HF vapor releasing, $XeF_2$**



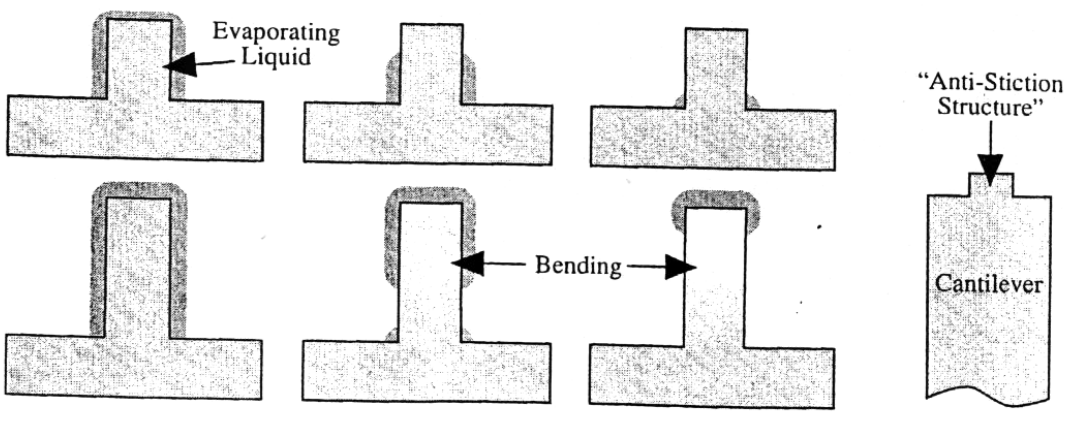
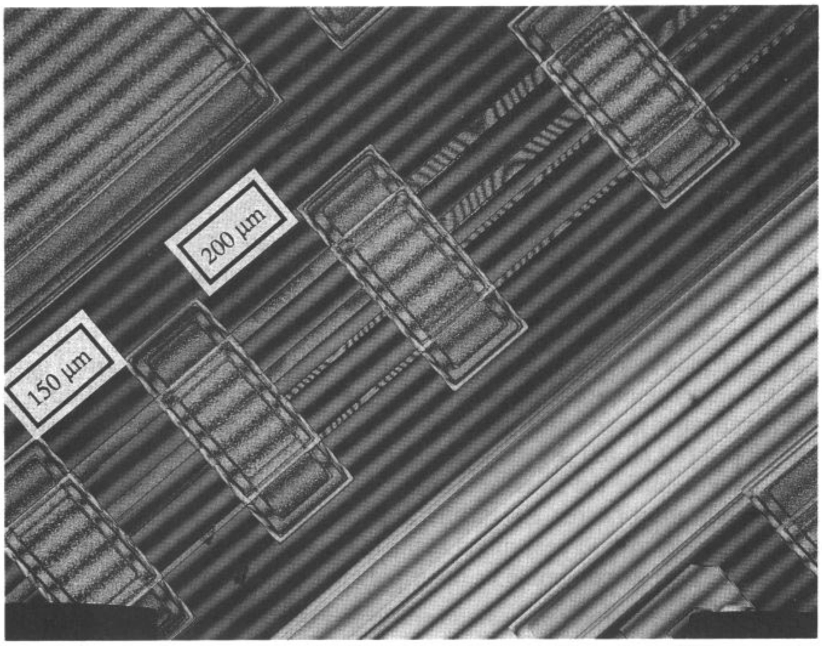




*Illustration of wet release drying modes for short cantilevers (top three diagrams left to right), long cantilevers (bottom three diagrams, left to right) and the "anti stiction structure" for improving cantilever release yield. After Abe, et al. (1995).*

- **Testing structure**




(a)

**Figure 4.17** Surface-micromachined bridge array for the evaluation of residual compressive strains in thin films: (a) optical interference micrograph of an array of polysilicon bridges; (b) theoretical buckling strains for the bridges in this array.

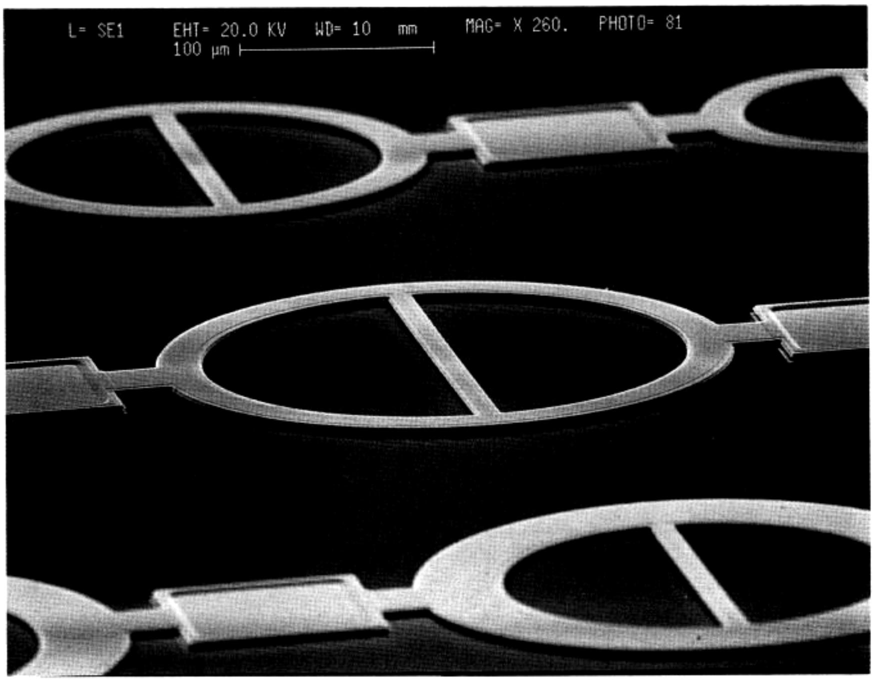
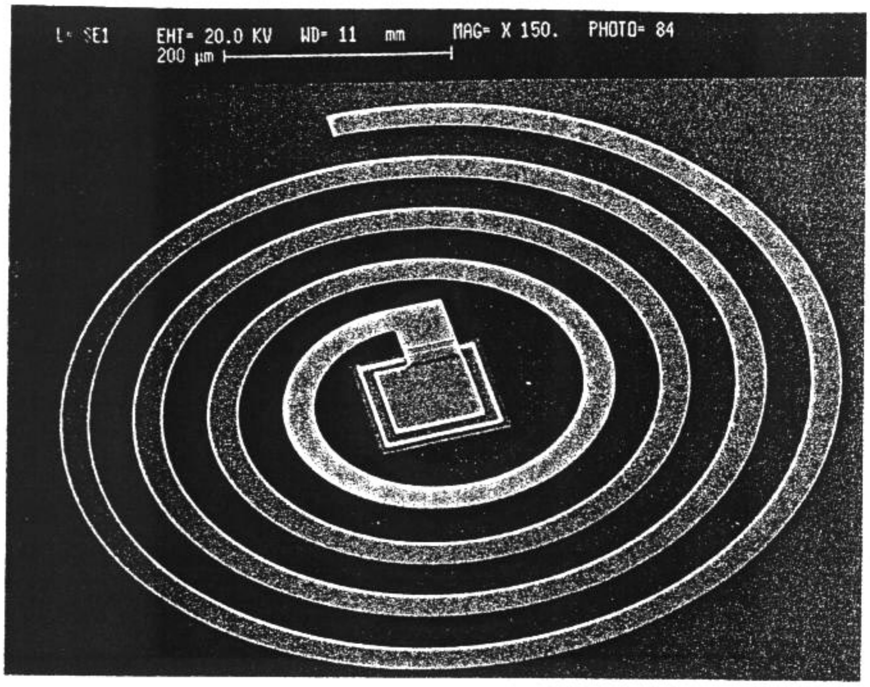



**Figure 4.18** Schematic drawing of a ring-and-beam micromechanical test structure for the measurement of residual tensile stress in thin films (after [47]).




SEM micrograph of a polysilicon Archemedian spiral structure used for the characterization of internal stress gradients.

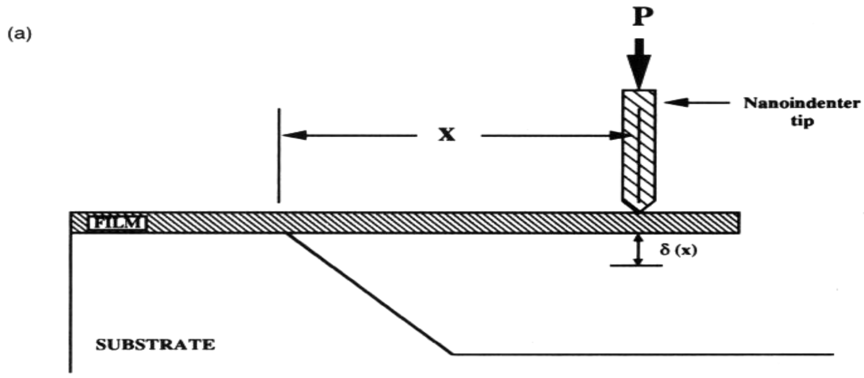



**Figure 4.21** Mechanical characterization of thin films using the Nanoindenter technique: (a) schematic drawing of the measurement technique (after [92]); (b) load-deflection data for a surface-micromachined polysilicon cantilever beam.

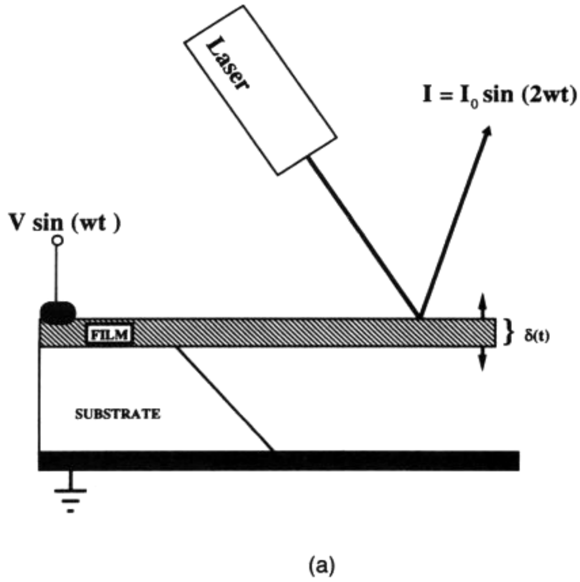



**Figure 4.22** Mechanical characterization of thin films using resonant frequency measurements: (a) schematic drawing of the experimental setup; (b) typical frequency response of an $SiO_2$ cantilever beam; (c) resonant frequency versus beam length for an array of $SiO_2$ beams.

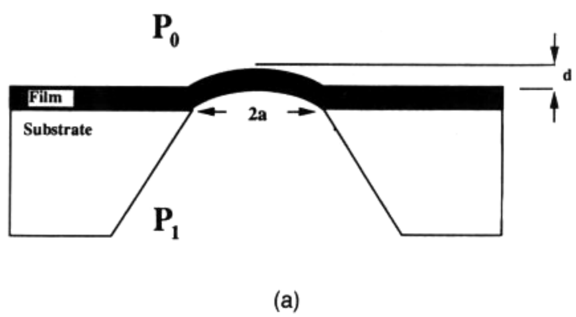



**Figure 4.23** Mechanical characterization of thin films with the membrane-deflection technique: (a) schematic drawing of the test structure; (b) pressure-deflection data for polyimide membranes.

- **Example: micro motor process**

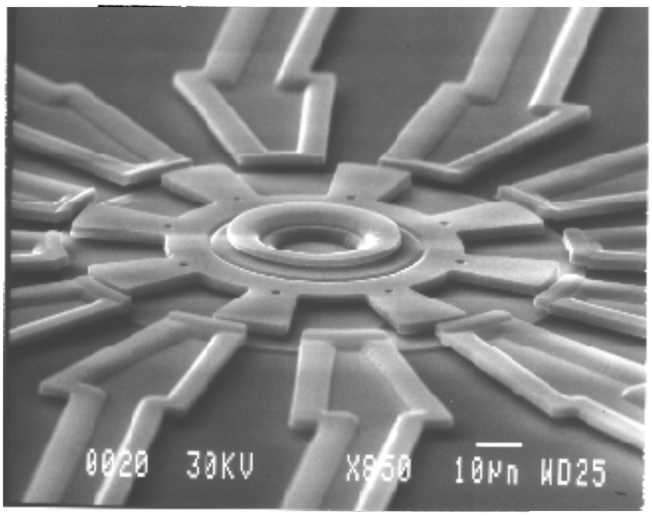



Fig. 1. A 12 stator-pole, 2.5 μm-gap, 100 μm-diameter, wobble micromotor with bushing 2 (i.e., the three small rotor indentations near the bearing).

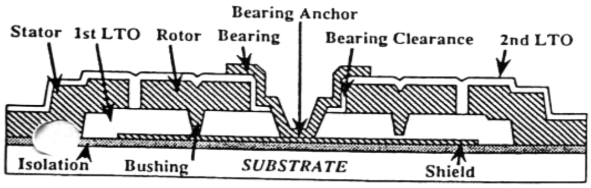
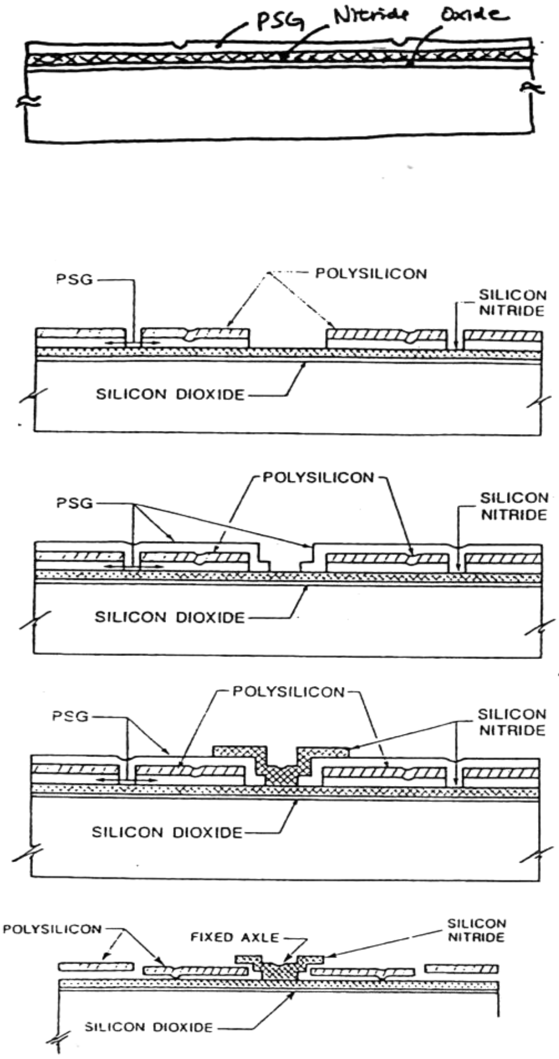



Fig. 2. Motor cross-section after fabrication completion and prior to release.




Reference:

Ljubisa Ristic, "Sensor Technology and Devices", Artech House, 1994.